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Design and construction of plywood movable hog houses

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DESIGN AND CONSTRUCTION OF PLYWOOD

MOVABLE HOG HOUSES

by

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INTRODUCTION

Justification for the Study

The past twenty years have witnessed a great change in housing structures for swine. From the centralized house the trend has been toward the lighter, movable structures. At first the movable hog houses, or individual houses as they were known then, were used more to supplement the centralized house than to replace it, but as the use of "clean ground" methods spread, an ever-increasing number of farmers began using movable hog houses to the exclusion of the centralized house.

However, as there were certain economies in labor and feed to be gained through the use of multiple pen houses, efforts were made to design movable houses of two, three, and even four pens. Of these designs only the two-pen house proved to be popular, for the others were far too heavy to be called movable houses.

Although the two-pen house is in wide use, it has its faults and for this reason swine herdsmen are alert for new type houses. Their dissatisfaction with present type houses is not due to a functional failure but to a structural failure: the failure to build a house light enough to be moved easily and still strong enough to withstand the stresses produced by many changes of location. W. A. Craft, Director, Regional Swine Breeding Laboratory, U.S.D.A., Ames, Iowa, (4) has summed up these points quite well in the following paragraph:

> "Portable houses aid materially in practicing rotation of pasture and hog lots, a necessary procedure in the control of parasitic infestations. There are two common objections to portable houses: (1) moving the houses makes it necessary to build them in small units to keep the weight down so that they may be moved with reasonable ease and without serious damage; (2) they require rather strong construction to protect them against damage when being moved which adds to the cost."

This excerpt clearly indicates the presence of a problem, but the mere presence of a problem does not always imply that an answer should be sought immediately. In this case, however, the problem is of sufficient importance to justify a study at this time. A brief survey of the number and value of hogs on farms in Iowa serves to bear out this contention. As estimated in Agricultural Statistics, 1939, (17) the number of hogs in Iowa on January 1, 1939, was 8,179,000 and their value was $116,141,800. An industry of such magnitude certainly justifies an investigation of one of the problems involved, especially when that problem is a major one.

The answer to the problem, it seems, must be found through better design and the adoption of lighter yet stronger building materials than are now in use. The use of plywood appears to be an excellent solution to the problem. Numerous tests have proved that plywood offers great strength with light weight. At the same time, the cost of plywood approaches more closely that of conventional lumber than any other building material. Therefore, this study will investigate the adaptation of plywood in the movable hog house.

Object of the Study

The objectives of this study may be listed as follows: (1) to design a plywood movable hog house to meet the criteria of light weight, low cost, great strength and rigidity, and maximum comfort for the hogs; and (2) to develop a simple procedure for the construction of the house designed to meet the above requirements.

REVIEW OF LITERATURE

Housing of Swine

The subject of housing for swine has been a popular one, and there is much information of a general nature available on the requirements and advantages of various types of hog houses. A resumé of the advantages and disadvantages of conventional movable houses as opposed to the centralized house may serve to bring out several points which must be considered in the design of houses for swine. Wilford and Kelley (20) have prepared such a resumé:

> "Advantages: 1. Pastures may be changed, providing more sanitary conditions and thus avoiding the use of diseased yards.
> 2. Provides shelter for hogs when hogging down corn.
> 3. Diseased animals may be isolated.
> 4. Affords renters and owners of small herds good shelter for their hogs at a small outlay of money.
> 5. Renter may own the houses and take them with him when he moves.
> 6. Fire risk is lessened.
>
> "Disadvantages: 1. Time and labor required for caring for hogs is greater than in a centralized house.
> 2. Feed storage and fresh water supply impracticable.
> 3. Less durable structures.
> 4. Advertising value less."

Although the above statement conveys some idea as to the features desired in a movable hog house, the requirements for an ideal hog house of any type need to be stated in a more specific form. Evvard and Davidson (8) give the essentials for any hog house as:

1. Warmth.
2. Dryness.
3. Abundance of light and direct sunlight.
4. Shade.
5. Ventilation.
6. Sanitation.
7. Safety and comfort.
8. Convenience.
9. Serviceability.
10. Sufficient size to shelter advantageously.
11. Durability.
12. Reasonably low first cost.
13. Minimum cost of maintenance.
14. Pleasing appearance.

This list of essentials has been shortened somewhat for the movable hog house by Wooley (21). He lists five requirements for a satisfactory movable hog house:

> "First, it must be built so that it can be moved from place to place with ease. Most houses are built on skids to facilitate moving. Second, the house must be built so that it can be opened up and sunned at intervals. Third, it must be so designed that it will be easy to clean. Fourth, these houses must be built strong where sows are shut in them,and fifth, it must be low in cost."

Existing type movable houses meet most of these requirements in design and construction. This study, therefore, is concerned mainly with the improvement of such houses through the use of plywood.

Properties of Plywood

The strength properties of plywood may be better understood if the nature of plywood is considered briefly. The Wood Handbook of the U. S. Forest Service (19) defines plywood in this manner.

> "Plywood is a term generally used to designate glued wood panels that are made up of two or more thin layers with the grain of one or more at an angle, usually 90°, with the others (Bureau of Standards, Navy and War Departments). The outside plies are called faces or face and back, the center ply or plies are called the core, and intervening plies, laid at an angle to the other plies, are called the crossbands."

A study of the manufacturing process also yields further information concerning the properties of plywood. An anonymous article in the American Builder and Building Age (2) describes the process thus:

> "Selected logs of Douglas fir, one of the two best structural woods in the world, are cut into "blocks", usually about nine feet long. The block is placed in a giant lathe and rotated against a long sharp knife which peels off the wood in a thin continuous ribbon of veneer, of the exact thickness desired, much as wrapping paper is unrolled. The ribbon of veneer is carried on conveyors to the clippers where defects are cut out and the veneer is clipped to desired widths. Next the veneer is sent through automatic driers to remove all but 2 or 3 percent of moisture, and then to the glue spreaders where expert workmen lay up the sheets crosswise in an odd number of plies, usually 3 or 5. The stacks of veneer sheets are placed in hydraulic presses and clamped under pressure of 150 pounds or more per square inch, until the glue has set stronger than the wood itself, transforming the sheets of veneer into strong, rigid panels of Douglas fir plywood. These panels are cut accurately to size, machine-sanded to a satin smoothness, and after a final check by Association inspectors are ready for a shipment."

From this description one may readily see that plywood approaches an equalization of strength properties along the length and width of the panel with a resulting decrease in dimension change and an increase in rigidity. The crossbands, which are responsible for these strength properties, also prevent excessive checking and splitting of the plies in any direction.

Advantages of Plywood Construction

The increase in rigidity of a wall framed with plywood over a wall framed with horizontal sheathing or diagonal sheathing has been demonstrated by tests at the United States Forest Products Laboratory at Madison, Wisconsin. As reported by the Douglas Fir Plywood Association (6), 1/4-inch plywood nailed on 9' x 14' wall panels makes a wall section that is 5.9 times more rigid than a similar section of horizontal sheathing and about 1.37 times more rigid than a similar section of diagonal sheathing. If the plywood is glued to the studs, the plywood wall section is 3 times as rigid as a diagonally sheathed wall and 7 percent stronger.

Another important advantage of plywood construction over lumber construction is the lighter weight of a plywood structure as compared with the weight of a conventional wood structure. Dunkelberg (7) and Crawford (5) found the weight of a plywood brooder house to be about 1/3 that of a conventional type brooder house of the same floor area. This decrease in weight was brought about through the use of lighter framing members and the use of 5/16-inch sheathing in the place of 1-inch boards.

The large panel sizes available in plywood are an additional advantage. The use of large size panels not only reduces labor costs in construction, but practically eliminates the infiltration of air through the walls and floor by reducing the number of cracks and openings.

An anonymous article in the American Builder and Building Age (2) summarizes the above mentioned advantages in this manner.

> "The special features which make fir plywood important to the construction industry are:
> 1. Large panel sizes.
> 2. Strength and rigidity both lengthwise and crosswise.
> 3. Practically no shrinkage or expansion.
> 4. Minimum of warping.
> 5. Non-splitting.
>
> "Large plywood panels meet the demand for a material with a minimum of joints, totally impervious to air, sturdy, yet handled easily by one man. Speedy, economical application is thus assured."

In summary it may be said that, considering the advantages of plywood over lumber and the relative costs of the two materials, plywood should be used in structures where light weight and rigidity are essentials which cannot be obtained through the use of conventional lumber. The movable hog house is such a structure. Therefore, it would seem that plywood offers a solution to the problem of designing a hog house which combines the essentials of light weight, great strength and rigidity, and greater comfort for the hogs.

THE INVESTIGATION

Preliminary Investigations

A comparative study of present type movable hog houses.

Objectives.

1. To become more familiar with the types of movable hog houses now in use.
2. Toprepare a size, weight, and cost chart for use in design.

Procedure. Material lists for eight different types of hog houses were secured from plans of the Midwest Plan Service and various other sources as indicated in Table I. From these material lists the cost of material was estimated using local prices. At the same time, the weight was estimated, actual weights being determined where possible. Lumber weights were computed on the basis of air dry lumber (12% moisture) weighing 34 pounds per cubuc foot. The labor cost in hours was taken from the "Field Manual for Inspection and Appraisal of Farm Insurance Risks" (9). A value of 50 cents per hour was then assigned and the actual labor cost in dollars figured. After the material cost and labor cost had been determined, they were added and the total cost secured. All costs were then found in terms of cost per square foot so that a definite cost unit might be had for comparing the houses.

Table I
Comparison of Present Type Movable Hog Houses

Type of House	Size	Cost: Material: $ Total	Cost: Material: $ Per Sq.Ft.	Cost: Labor: $ Total	Cost: Labor: $ Per Sq.Ft.	Cost: Total: $ Total	Cost: Total: $ Per Sq.Ft.	Wt. in Lbs.
Iowa "A" No Floor (11)	7x7	12.72	.26	2.75	.06	15.47	.32	419
Iowa "A" With Floor (11)	7x7	19.75	.40	3.25	.07	23.00	.47	674
Modified "A" (12)	6x8	22.22	.46	3.90	.08	26.12	.54	737
Shed Roof (18)	6x8	28.37	.59	4.35	.09	32.72	.68	942
Texas "A" (16)	7x8	29.60	.53	4.30	.08	33.90	.61	1056
Gable Roof (15)	6x8	33.61	.70	6.00	.13	39.61	.83	1055
Comb. Roof No Floor (14)	8x12	36.61	.38	5.20	.06	41.81	.44	1140
Comb. Roof With Floor (14)	8x12	49.74	.52	6.50	.07	56.24	.59	1530
Straw Loft (13)	8x14	74.56	.67	10.55	.09	85.11	.76	2505
Three-Pen No Floor (10)	8x18	51.65	.36	7.35	.05	59.00	.41	1544
Three-Pen With Floor and Partitions (10)	8x18	76.80	.53	11.35	.08	88.15	.61	2418

Note: Cost of painting not included.

Conclusions. 1. Of the one-pen houses studied, the "A" type is the lightest and cheapest; the shed roof, second; and the gable roof, third.

2. Among the multiple-pen types, considerable variation in cost and weight is found, with the weight and cost being influenced both by the size of the house and by the type of construction used.

3. Present multiple-pen houses with floors are entirely too heavy to be moved easily.

Experimental

Preliminary design.

Size. In the design of a movable hog house, as in the design of any type of structure, certain features must comply with common usage. The size of pens in this case is one of these features. The accepted size of a pen for portable houses is 6' x 8'. There is some variation, but experience has shown that this is the optimum size for the average farm.

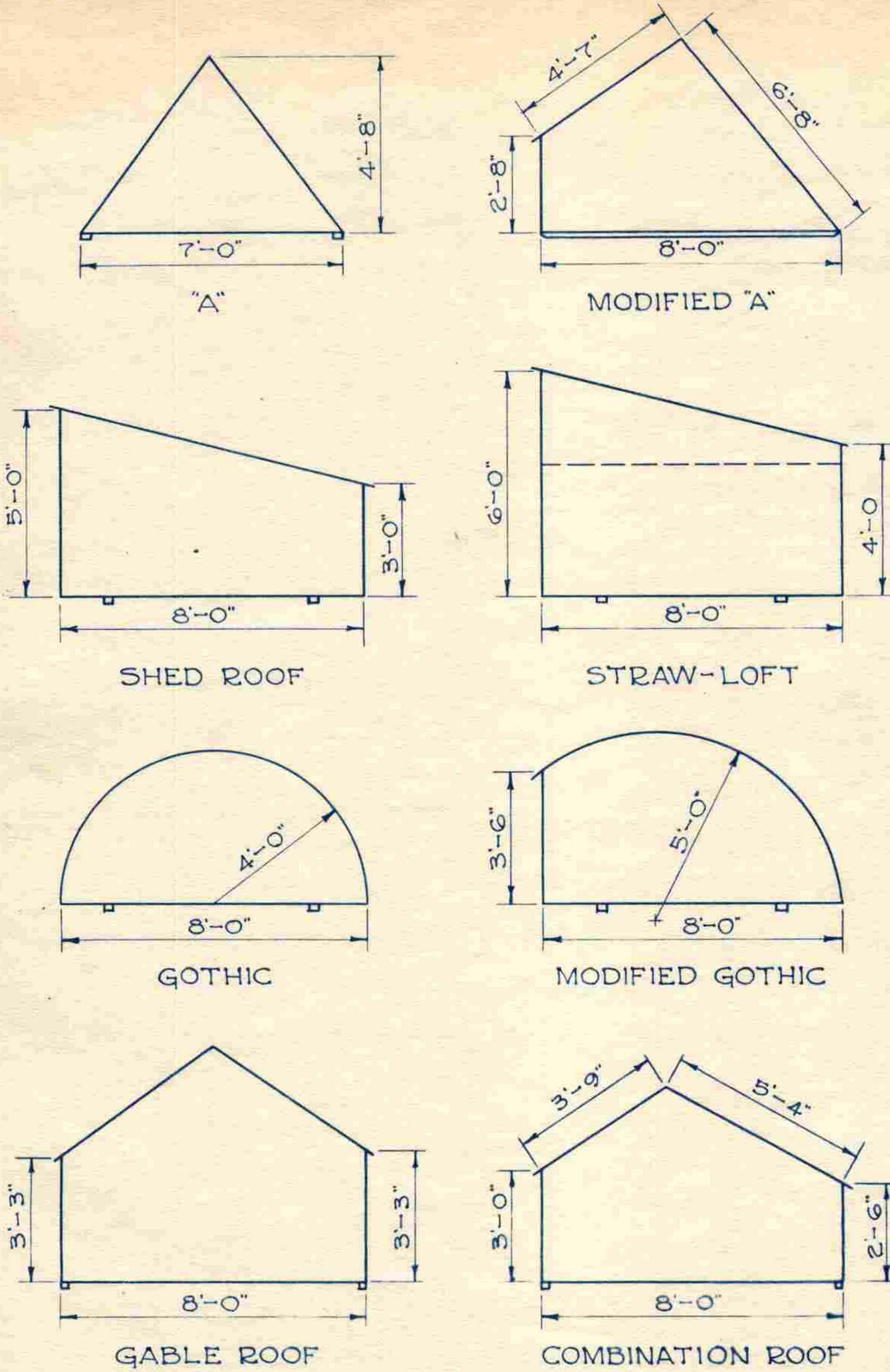
The number of pens in the house was chosen as three. This number represented a compromise between maximum allowable weight, economy of materials in construction, and economy of labor in caring for the hogs. This choice was substantiated by Craft (4) who said such a house should meet the needs of a large group of farmers.

Shape. The most desirable shape for a movable hog house was the subject of an intensive study. All of the shapes shown in Figure 1 have certain features which are desirable. The "A" type is simple to construct, requires no guard rails, and weighs very little. This shape, however, decreases the available floor area, is difficult to move without tearing up, and, in general, is more suited for use as a range shelter than for use as a shelter during and following the farrowing period.

The modified "A" type has much the same advantages and disadvantages as the "A" type. This shape requires a guard rail along one side, weighs slightly more, and restricts floor area in the same manner as the "A". The shed roof house overcomes most of the above-mentioned disadvantages, but must be eliminated as no roof doors can be used. The straw loft house is only a special type of shed roof and receives the same consideration.

The gothic roof shape, while quite advantageous in the design of a plywood brooder house, merits very little consideration here since it would have to be built without roof doors and without shade doors. A modified gothic shape, which would make possible the use of shade doors, was studied, but difficulties of construction and the inability to provide roof doors caused the abandonment of its use.

The choice of shapes was finally narrowed down to the gable roof and the combination roof. Both shapes provide for entrance doors, shade doors, and roof doors, both withstand



Feg. 1. Possible Shapes for Movable Hog Houses

the strain of moving better than other types, and in addition, the entire floor area is available for the hogs.

The final choice in favor of the combination roof shape was based upon two important considerations: (1) this shape provides maximum floor area with the minimum of air space, and (2) it permits the use of shorter panels. The importance of these two points should be stressed. Extra air space means a greater volume of air to be warmed. Inasmuch as the sows must provide all of the heat in the house, the air space must be kept low. The second point means that a 6-foot panel of plywood can be so cut as to furnish a section for both front and rear walls, whereas with the gable shape, an 8-foot panel would be required. Thus the economy of the combination roof shape was the deciding factor in its use.

Number and size of openings. The use of three doors in each pen of a movable hog house has become fairly well established. All of the designs studied in the first part of the investigation make use of an entrance door, a shade door, and a roof door. The gable house provides, in addition to these three, a small vent door in the end of the house. Since the three-door pen is so common and seems to work so well, its use was continued in the three-pen plywood movable hog house.

The size of the entrance doors was taken as 2' x 3'. Although these dimensions are very close to the minimum desired, they were chosen because they fit into the framing pattern for plywood so well. The width of the roof doors was determined by the rafter spacing of 2'-0" on centers, and their length was determined by the width of the front roof section.

The height of the shade doors was determined by the height of the rear wall section. The width of these doors was chosen as 4 feet in order to provide a 2-foot brace member of each end of the rear wall section and a similar brace member near the center of the section.

<u>Height of walls</u>. The use of a front wall height of 3'-4" and a rear wall height of 2'-8" makes possible the cutting of a panel for both walls from a 6'-0" panel of plywood. At the same time these dimensions meet the minimum requirements for door heights.

<u>Pitch of roof</u>. The decision to use 4'-0" on the front roof and 6'-0" on the rear roof determined the pitch, for after a 3-inch lookout and a 3-inch lap had been deducted from the above dimensions, only one combination for roof pitch would satisfy the resulting rafter lengths.

<u>Grade of plywood</u>. The determination of grades of plywood to be used in the various sections of the structure was based upon the expected moisture content of the wood under actual conditions. While the moisture content of the wood inside a movable hog house is very high, the glue used in sheathing grade plywood is highly water-resistant. For this reason plyscord sheathing was chosen for all interior surfaces. Quite different was the problem of choosing the proper grade for the outside surfaces. There the wood is subject to rain and snow, a condition which will send the moisture content of the wood to a very high level. This also means great fluctuations in

percentage of moisture and this fluctuation is almost as severe on the glue bond as is the high moisture content. Therefore, an exterior grade of plywood was specified for the walls and ends. Faces of Sound 2 sides were specified because utility or sheathing faces could not be secured in the exterior grade of plywood.

Method of fabrication. As has already been pointed out, plywood offers the greatest degree of strength and rigidity when used with glued construction. Since glue also acts as a seal to prevent the infiltration of air at joints, its use would seem advisable in spite of the slight increase in cost. All joints upon which the rigidity of the structure depends should be glued; this leaves only the spiking of the guard rails to the studs and the fastening of the partitions to the rafters to be done in the conventional manner. Since casein glue requires pressure while setting, the use of nails spaced approximately 5 inches apart was decided upon to provide the pressure. Glue should be well spread on only one surface of the joint.

Prefabrication of sections. The construction procedure decided upon was the prefabrication of sections and then the assemblage of these sections. This procedure was adopted because much of the construction of small, supplementary buildings for the farmstead is done in the lumber yards of the state. A system of this kind would be an advantage in that the sections could be built in the lumber yard by skilled laborers where power equipment is available. The sections could then be loaded on a truck and hauled to the farm, where the entire structure could be assembled. The system would provide for the lowest possible labor cost and the highest quality of workmanship.

Conclusions. The conclusions drawn from preliminary design experience are:

1. A three-pen house 8 feet by 18 feet appears to be a justifiable compromise between maximum allowable weight, greatest convenience and serviceability, and economy of materials.

2. The combination roof house is an excellent shape, for it permits the use of roof doors and shade doors, while at the same time it provides maximum floor area with minimum air space and greatest economy of materials.

3. Glued plywood construction has important advantages which should be considered and used in the construction of a plywood hog house.

Design.

Determination of loading conditions. Before any structure can be designed, a design load must be determined. In the case of structures for swine there seemingly have been no loading conditions set forth. Therefore, a decision as to what loads and conditions of loading would give maximum stress in the material had to be reached.

From suggestions of various members of the Animal Husbandry Staff of Iowa State College, the following schedule of loads was adopted:

Sow at farrowing time	600 pounds
Sow and pigs at end of weaning period	850 pounds
Pigs, bedding six to the pen ...	1,500 pounds

Inasmuch as the first load of 600 pounds is concentrated on four points or less while the others are distributed, the first load was taken as the maximum design condition. The bending moment caused by the weight of the material was disregarded in all cases because it represented such a small proportion of the total.

Assumptions in design. As the structural properties of plywood have not as yet been fully investigated, certain assumptions must be made which, if they are in error, err on the side of safety. The assumptions made in this design problem were:

1. Except where stated otherwise, plywood is to be considered as being placed so that the grain of the face plies is parallel to the span.

2. The glued construction specified in the preliminary design justifies considering all glued joints as being rigid.

3. Allowable fiber stress of Douglas fir lumber in flexure is to be taken as 2,000 pounds per square inch. Allowable fiber stress of Douglas fir plywood is to be taken as 1,800 pounds per square inch.

4. In computations for stress in extreme fiber from flexure, the formula $S = \frac{Mc}{I}$ is to be used, where

S = allowable fiber stress.
M = maximum bending moment.
c = distance from extreme fiber to neutral axis.
I = moment of inertia; in the case of plywood, only those plies with grain parallel to the span are to be considered.

5. Where plywood is glued to joists, studs, etc., these members are to be considered acting as T-beams.

Discussion of assumptions. The reason for specifying that the grain of the face plies of plywood be parallel to the span is self evident. The moment of inertia of the plywood acting as a beam is greatest in this position. Therefore, the resulting stress in flexure will be a minimum for any particular loading conditions.

Glued construction may be considered rigid because the bond developed by the wood and the glue is such that the entire joint acts as a solid piece of wood. There is rotation at the joint, but the relative positions of the members framing into the joint remain unchanged.

The value of 2,000 pounds per square inch for number one common Douglas fir lumber, although in excess of the allowable value for urban construction may be justified for use in this design problem. The Wood Handbook of the U. S. Forest Service (19) lists the basic stress for clear specimens of Douglas fir lumber at 2,333 pounds per square inch. The adoption of a design value of 2,000 pounds per square inch affords a safety factor to take care of the fact that number one common Douglas fir is not clear, but has a small percentage of defects. Then, too, as pointed out under the loading conditions, the design load is a maximum and a high safety factor is unnecessary. Aside from this approach to the safe design value, the use of higher stresses in rural construction than are permitted in urban construction is justifiable in view of the fact that in most rural construction there is no risk to either human or animal life. Therefore, a slight risk of property loss may be justified if a great saving in material costs results. The value of 1,800 pounds per square inch for plywood is the recommended value of the Douglas Fir Plywood Association. This value was not increased as was the value for lumber because the slight taper of grain in each ply of plywood which results from the method of manufacture justifies a slightly lower design stress. The taper of grain in the plies is a result of cutting the plies in a horizontal plane from a tapered log.

In the absence of better information, the basic formula for computing extreme fiber stress in flexure was adopted. Plywood does not act quite the same as solid wood of equal thickness and perhaps some error was introduced here. Considering the moment of inertia of only those plies with their grain parallel to the span restricts any error to the safe side of allowable stress rather than the dangerous side. As a check on this assumption, however, the stress in the floor was computed by the formula developed by the U.S. Forest Service

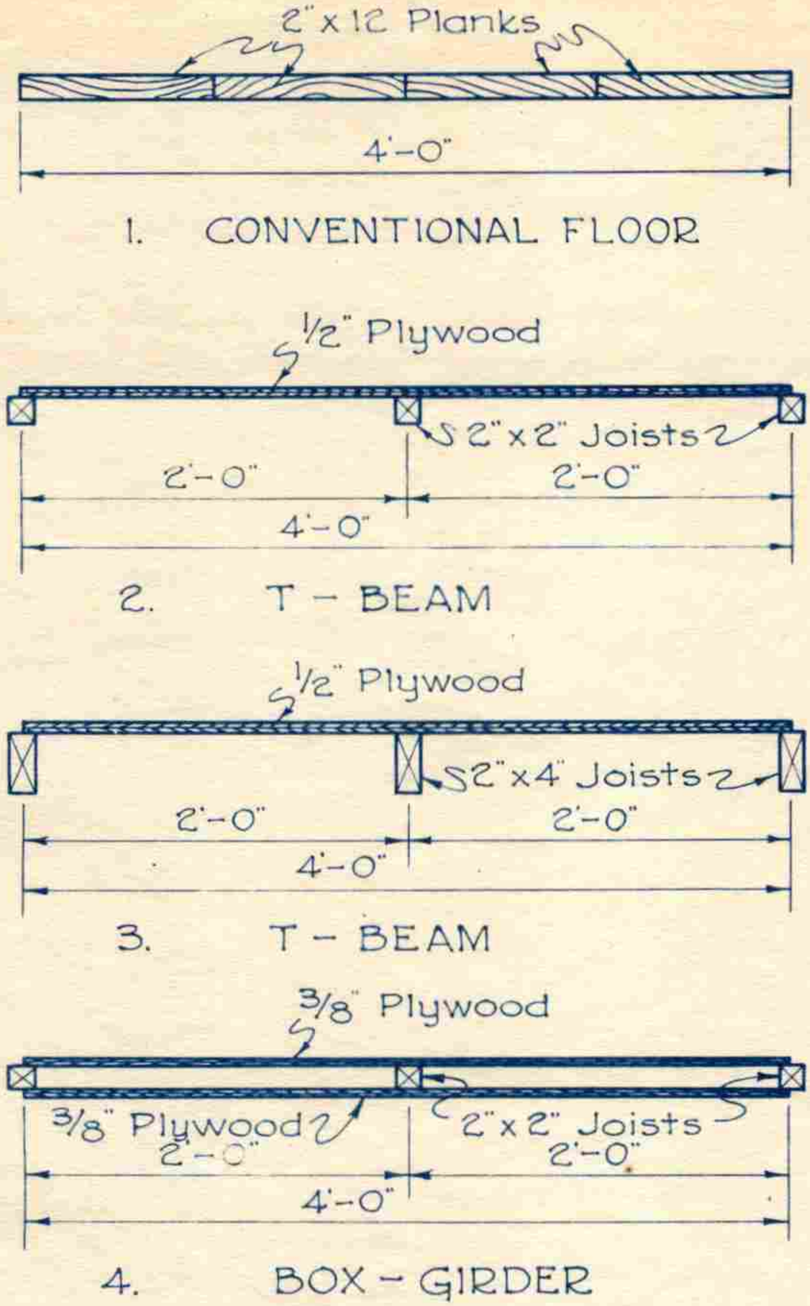
(19). This formula is $M = \frac{KSI}{c}$ where:

- M = bending moment.
- K = a factor depending upon the number of plies and direction of face grain; for 1/2-inch plywood K = 0.85.
- S = the modulus of rupture of the solid wood.
- I = the moment of inertia about the neutral axis of only those plies which have their grain parallel to the span.
- c = the distance from the neutral axis to the outer fiber of the outermost ply having its grain parallel to the span.

The factor of safety found by this computation checked very closely with that computed by the basic stress formula.

The last assumption is supported by the findings of R. E. Luxford as reported in American Architect and Architecture (3) in regard to studs covered with plywood. The results of his tests show that, where plywood is glued to the studs, the panel acts essentially as a box girder. When one covering is thrown into tension, the other is placed in compression. On the basis of this evidence, the assumption that plywood may act as the flange of a T-beam seems reasonable enough.

Floor section. Numerous factors enter into any problem of design, but sifficient strength to carry the load and light weight were the primary factors in floor design. Preliminary floor sections of four types (Figure 2) were designed for two conditions of loading: (1) a concentrated load of 600 pounds in the center of the span, and (2) a uniform load of 150 pounds per linear foot over 4 feet. In the case of plywood



RESISTING MOMENT OF SECTION	
SECTION	MOMENT (in.-lb.)
1	16,660
2	9,330
3	35,900
4	39,000

Fig. 2. Possible Floor Sections for Plywood Movable Hog Houses

panels, a 4-foot width was taken as the supporting unit, while for the conventional floor a 2-foot section was taken as the supporting unit.

From the above designs Type 2 of Figure 2 was chosen as meeting the weight and height requirements and was investigated further. First, the thickness of plywood required to transmit the load to the joists was investigated by considering the plywood as a 2' x 4' panel, fixed all around its perimeter, with a load distribution ratio of the short span to the long span of two. A concentrated load of 300 pounds was considered as being placed in the center of the panel and the stress in extreme fiber computed for an effective width of 30 inches for the short span and 24 inches for the long span. From this computation 1/2-inch plywood was found to meet the requirements. Later 5/8-inch plywood was ordered for the construction of the house as this thickness could be obtained in less time.

The 2" x 2" joists were checked by considering two concentrated loads of 150 pounds each, distributed one foot apart about the center line of two T-beam joists. The construction of the joists was taken as a 2" x 2" stem with a flange of 1/2 inch plywood 10 inches wide. The span of the joists was taken as 4 feet. From these computations stresses were found to be within the allowable values and therefore this design was specified.

The choice of Floor Type 2 brought up the problem of the number and size of runners for use under the floor. From

Table II

Material List, Movable Hog House -- 8' x 18'

Lumber Items	Grade	Pcs.	Size	Length	F.B.M.	Est. Price	Amount
Runners	1 com.	2	4x6	18'-0"	72	$60.00	$ 4.32
Crosspieces	1 com.	2	4x4	8'-0"	22	60.00	1.32
Floor	1 com.	9	2x12	16'-0"	288	60.00	17.28
Studs	1 com.	6	2x4	16'-0"	64	53.00	3.39
Plates & ridge	1 com.	3	2x4	20'-0"	40	55.00	2.20
Headers	1 com.	1	2x4	18'-0"	12	55.00	.66
Pig fenders	1 com.	2	2x4	18'-0"	24	55.00	1.32
Pig fenders	1 com.	1	2x4	12'-0"	8	53.00	.42
Pig fenders	1 com.	3	2x4	8'-0"	16	53.00	.85
Ends	1 com.	3	1x12	16'-0"	48	65.00	3.12
Ends	1 com.	2	1x12	12'-0"	24	65.00	1.56
Battens for ends	1 com.	7	1x4	10'-0"	24	65.00	1.56
Ties & braces	1 com.	2	1x6	8'-0"	8	65.00	.52
Partitions	1 com.	10	1x4	16'-0"	54	65.00	3.51
Partitions	1 com.	2	1x4	12'-0"	8	65.00	.52
Partitions	1 com.	2	1x4	10'-0"	8	65.00	.52
Roof	1 com.	16	1x12	12'-0"	192	65.00	12.48
Bats	1 com.	18	1x4	6'-0"	36	65.00	2.34
Bats	1 com.	6	1x4	8'-0"	16	65.00	1.04
Cleats	1 com.	3	1x6	12'-0"	18	65.00	1.17
Cleats	1 com.	2	1x4	16'-0"	11	65.00	.72
Dropsiding	1 com.	39	1x6	6'-0"	117	65.00	7.61
Flooring, rear doors	1 com.	3	1x6	6'-0"	9	65.00	.59
TOTAL							$69.02

Hardware Items	Quantity	Est. Price	Amount
Strap iron 1/4" x 1-1/4" x 2'-6"	4	$ .15	$ .60
Hinges, rear doors - 6"T	5	.35	1.75
Hinges, front doors - 5"T	3	.30	.90
Hinges, roof door - 5" strap	3	.25	.75
Machine bolts, washers - 1/2" x 7"	4	.07	.28
Hasps - 8" hinge	6	.35	2.10
Nails - 16 d com.	2#	.05	.10
10 d com.	2#	.05	.10
8 d com.	8#	.05	.40
6 d com.	3#	.05	.15
Screws - 1-1/4 x 10	14 doz.	.05	.70
Paint	1-1/2 gal.	3.55	5.30
TOTAL			$13.13

TOTAL $82.15

personal experience, Craft (4) recommended the following combinations of size and spacing:

Spacing	Size
4' x 0"	4" x 4"
6' x 0"	4" x 6"
8' x 0"	4" x 6"

When a brief review showed that supports 4'-0" on centers were necessary to support the floor, 4" x 4" runners were chosen. Other reasons justifying this selection were: (1) the overall height of the floor is kept below 8 inches, a satisfactory height to which small pigs can climb without strain, and (2) the weight of three 4" x 4" runners is slightly less than the weight of two 4" x 6" runners.

One other recommendation was thought advisable in the floor plan. Stiffeners of 2" x 4" material were placed on top of the runners between the joists in order to provide additional strength and rigidity and sufficient glued area in contact at the joints to make certain of a rigid joint.

Wall sections. Again the questions of design load and load conditions had to be settled. The load on the wall would quite evidently be an impact load caused by a 600 pound hog running against the structure. This load would create a maximum moment on the front section, since it has a clear vertical span of 3'-0" as opposed to 2'-4" for the rear section. The load decided upon was a uniform load of 75 pounds per square foot over a 3' x 4' section or a total load of 900 pounds.

The spacing of the framing was governed largely by the

Table III
Material List, Plywood Movable Hog House No. I

Lumber Items	Grade	Pcs.	Size	Length	F.B.M.	Est. Price	Amt.
Skids	1 com.	3	4 x 4	18'-0"	72	$60.00	$4.32
Joists	1 com.	4	2 x 2	16'-0"		.02	1.28
Joists	1 com.	2	2 x 4	16'-0"	22	53.00	1.17
Girt and end	1 com.	1	2 x 2	16'-0"		.02	.32
rafters	1 com.	2	2 x 2	12'-0"		.02	.48
Door framing	1 com.	8	2 x 2	12'-0"		.02	1.92
Floor stiffeners	1 com.	3	2 x 4	18'-0"	36	55.00	1.98
Shoe sill	1 com.	2	2 x 4	18'-0"	24	55.00	1.32
Plate	1 com.	2	2 x 4	20'-0"	27	55.00	1.49
Ridge	1 com.	1	2 x 4	20'-0"	14	55.00	.77
Studs and rafters	1 com.	12	2 x 4	12'-0"	96	53.00	5.09
Guard rails	1 com.	6	2 x 4	12'-0"	48	53.00	2.54
Total							22.68

Plywood Items	Grade	Pcs.	Size	Thickness	Est.Price	Amount
Floor	Plyscord sheathing	5	4'x 8'	1/2"	$.115	$18.40
Roof	Plyscord sheathing	7	4'x 8'	5/16"	.065	14.55
Ends	So2S DFPA-Ext.	2	4'x 8'	1/2"	.18	11.52
Sides	So2S DFPA-Ext.	5	4'x 6'	1/2"	.18	21.60
Partitions	Plyscord sheathing	2	4'x 8'	3/8"	.08	5.12
Total						71.19

Hardware	Quantity	Est.Price	Amount
Glue, Casein water resistant, self-bonding	10#	$.275	$ 2.75
5" T hinges	3 pr.	.30	.90
4" T hinges	6 pr.	.25	1.50
6" hasps, hinge	6	.30	1.80
12 doz. 1-1/4 x 10 screws	12 doz.	.05	.60
Roofing, 45# roll	2 sqs.	1.50	3.00
Bolts, 1/2" x 4-1/2"	6	.05	.30
Strap iron 1/4" x 1-1/2" x 2'-6"	2		.40
G. I. roof edging 3/4" x 1-1/4"	20 lin. ft.	.035	.70
Nails - 4 d com.	5#	.05	.25
6 d com.	8#	.05	.40
10 d com.	4#	.05	.20
16 d com.	3#	.05	.15
3/4" roofing nails	1#	.05	.05
Paint, aluminum metal paint	1-1/2 gal.	3.55	5.30
Creosote	1/4 gal.		.20
Total			18.50

TOTAL $112.37

number and sizes of doors. The studs on the front and back were spaced so that the doors were framed properly. Studs of 2" x 4" material were selected for simplicity of construction and then investigated to determine if they could carry the impact load when spaced as above. Considering the studs as cantilever beams, the stress exceeds the allowable of 2,000 pounds per square inch by 200 pounds per square inch. However, since plywood panels were fastened with glue to the studs, the unit then acted as a T-beam and further investigation found the above size of studs to be satisfactory.

The thickness of plywood was determined by considering the same load but taking the plywood as a fixed beam with a span of three feet. Using maximum fiber stress of 1,800 pounds per square inch, the thickness of plywood required was found to be 1/2 inch.

Roof section. The spacing of rafters was arbitrarily taken as 2'-0" on center so that the roof doors might be framed with the least difficulty. For ease of construction 2" x 4" pieces were used. Both the spacing and size of members were more than sufficient to support the roof load which was taken as 20 pounds per square foot of roof area. The thickness of sheathing was determined by treating the plywood as a two-span continuous beam simply supported. Sheathing plywood of 5/16-inch thickness was found to have a high enough resisting moment to keep the extreme fiber stress below 1,800 pounds per square inch. The use of sheathing grade plywood covered will roll roofing was found to be lower, both in cost and in heat loss, than an exterior grade of plywood and for that reason was used.

Conclusions. The design experience justifies the following conclusions:

1. A 600 pound load concentrated on four points is a safe design load for the structure.

2. Certain assumptions must be made as to the action of glued plywood construction.

3. A floor section of three 4" x 4" runners 4'-0" on centers supporting a T-beam floor, consisting of 2" x 2" joists 2'-0" on centers and 1/2 inch plywood as sheathing is the most satisfactory floor.

4. A wall section of 2" x 4" studs covered with 1/2-inch plywood is the best wall design.

5. A roof section of 2" x 4" rafters 2'-0" on centers covered with 5/16-inch sheathing and roll roofing is a satisfactory roof design.

Construction.

Introduction. No matter how carefully ideas conceived and executed on the drafting table are studied, difficulties are quite likely to be encountered in actual construction. For this reason one of the objectives of the study was to construct a full-size plywood movable hog house and to set up a simple method of procedure.

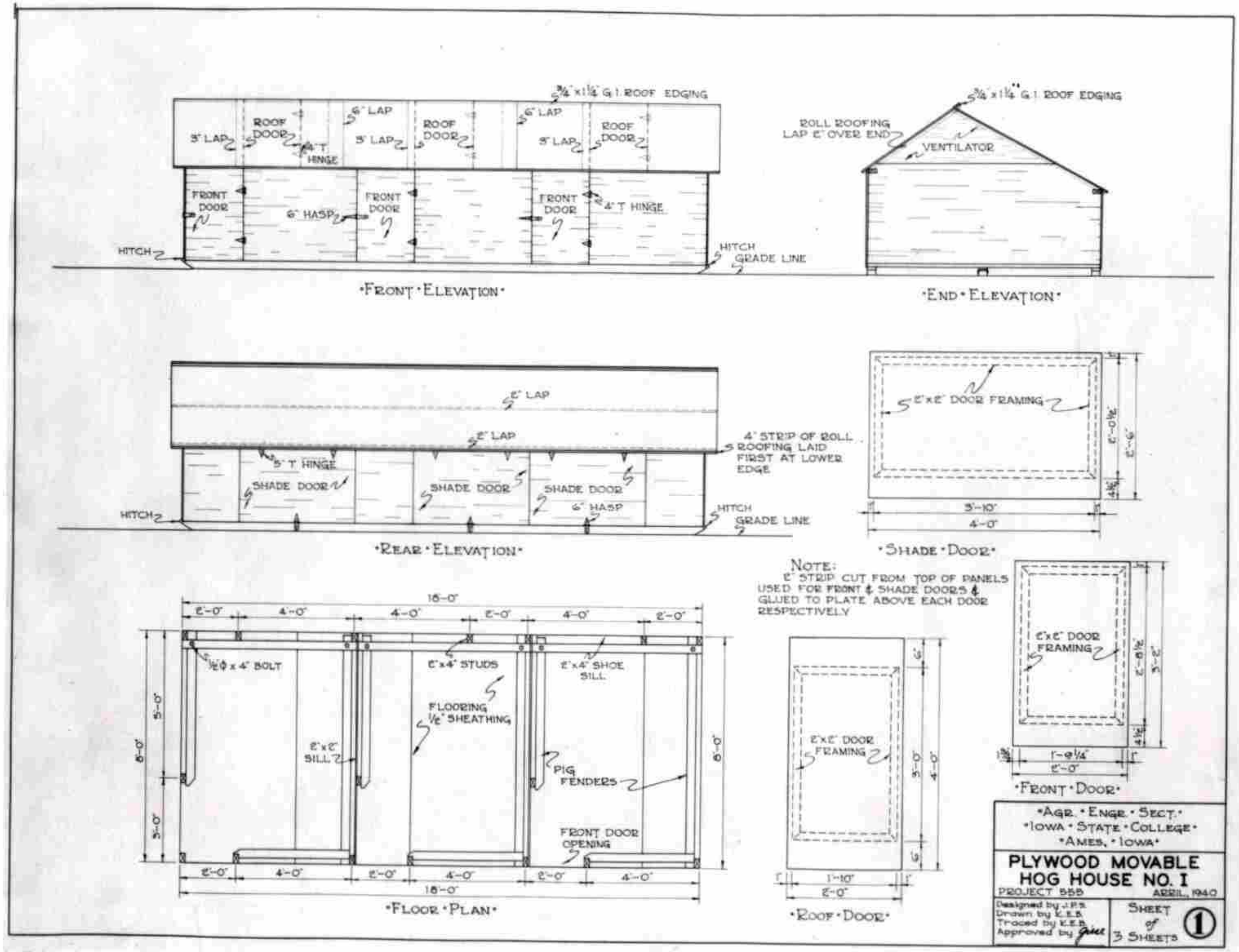


Fig. 3a. Design of Plywood Movable Hog House No. I

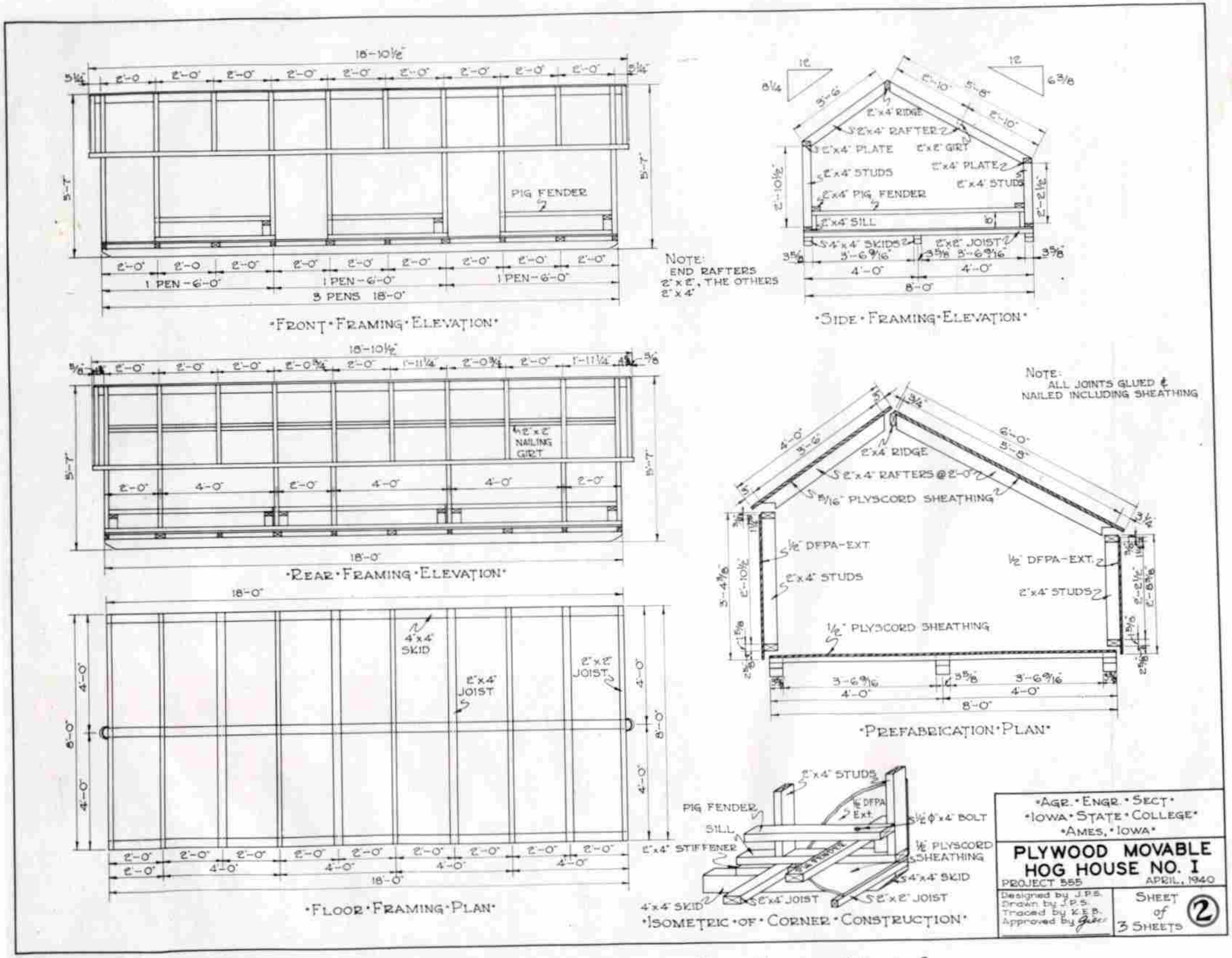


Fig. 3b. Design of Plywood Movable Hog House No. I, continued

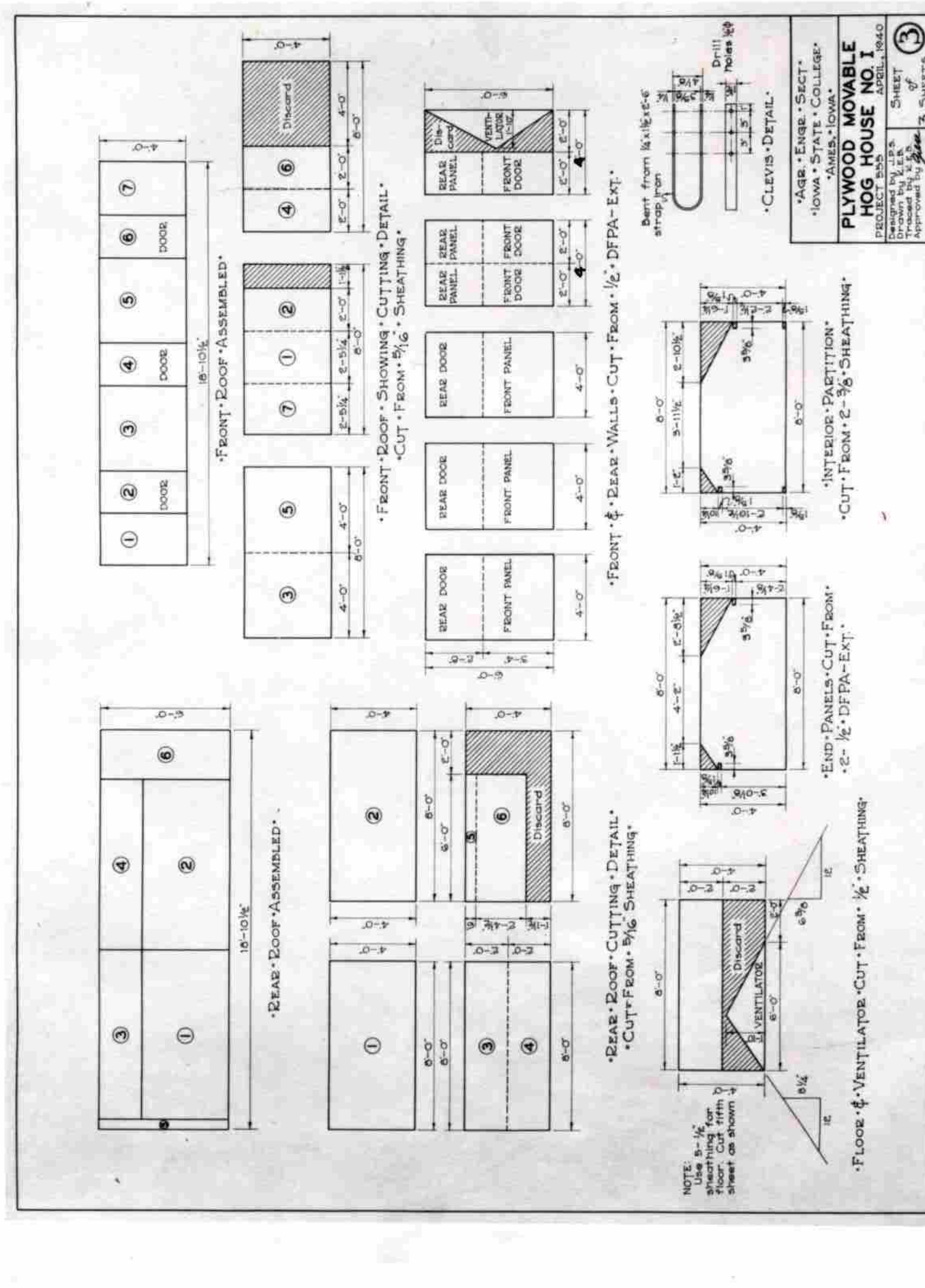


Fig. 3c. Design of Plywood Movable Hog House No. I, continued

Scale models. The difficulty of securing exact scale material for plywood precluded the possibility of building and testing a scale model of the three-pen movable plywood hog house. However, thin plywood closely approaching a scale of 3" = 1'-0" was available and, therefore, the decision was reached to construct a scale model of one pen of the house so as to develop a construction procedure. Three scale models were constructed; each differed slightly in the technique of construction. In this manner a procedure for construction suitable for use on a full-scale structure was developed.

Plywood movable hog house No. I. The system of construction followed was one of prefabrication by sections and assemblage of the sections.

After the runners, joists, stiffeners, and plywood for the floor had been cut to size, the three runners were laid out 4'-0" on center on a level surface. Then the clevis hitch was placed on each end of the center runner. A sheet of plywood was placed across each end of the runners to serve as a straight edge and square. Following this the joist spacing of 2'-0" on centers was marked off on the runners, glue was spread on the ends of the joists, and the joists were fastened in place. The stiffeners were spread with glue and fastened to the runners and then the plywood sheathing was applied, the glue being spread just ahead of the placing of the plywood. The completed floor is shown in Figure 4.

When the remaining framing members had been cut, the shoe

Fig. 4. Floor and Roof Sections

Fig. 5. Rear Wall Section

Fig. 6. Front Wall Section

sill, studs and plate for the front wall section were laid out on the floor section. (The floor section was used as a straight edge and level surface.) The spacing of the studs was marked on both the shoe sill and plate and the studs were end-nailed in place. After glue had been spread on the framing members, the front plywood panels were fastened in place (Figure 6). The rear wall section was fabricated in the same manner using the correct lengths of members (Figure 5).

In the construction of the rear roof section, the rafters were laid out on the floor according to the spacing shown on the plan for the house. After the beveled ridge had been nailed in place, glue was spread on the rafters and the roof sheathing fastened in place. Following this the nailing girts were placed and the false end rafters were glued in position.

The front roof section was slightly different in that it had to be constructed in four sections. For two of the sections, three rafters were spaced 2'-0" on center, glue was spread on the rafters, and the plywood panels fastened down. The other two sections were framed in much the same manner, so that one of the sections was the left hand pattern of the other. In each case two rafters were spaced, glue was spread, and the plywood panel fastened in place. Then the false end rafter was glued in position.

In the assembly process the floor section was leveled by blocking under the ends of the runners. Some deflection in the center of the floor span occurred, but this deflection was too slight to require correction. After glue had been spread along the overlap and bottom of the shoe sill of the front section, that section was set in place on the floor and pressure applied by the use of nails. The rear roof section was treated in a similar manner. (Figure 7). Then before the glue had had time to set, the end panels were cut, glue spread on the end studs, and the panels fastened securely. The use of square corners of the plywood was the easiest and quickest method of squaring the house. After the 2" x 2" floor strip had been glued in place, the interior partitions were cut and glued to the proper floor strip and studs (Figure 8).

After the front and rear roof sections had been lifted into position, they were spiked together at the ridge and the sheathing of the front section nailed to the ridge and plate. The sheathing of the rear roof section was then nailed to the other plate. Nails were spaced about five inches on centers. Following this the partitions and end walls were nailed to their respective rafters.

Framing of the doors was the next step of the procedure. The front doors and shade doors needed no extra framing, but the roof doors did, so 2" x 2" framing members were used on all doors for consistency in construction. After the header strip of 1-1/2 inches had been cut from the top of all the plywood door panels, the framing was cut according to the detail plan and glued to the plywood panels. After the glue had set, the doors were hung in place.

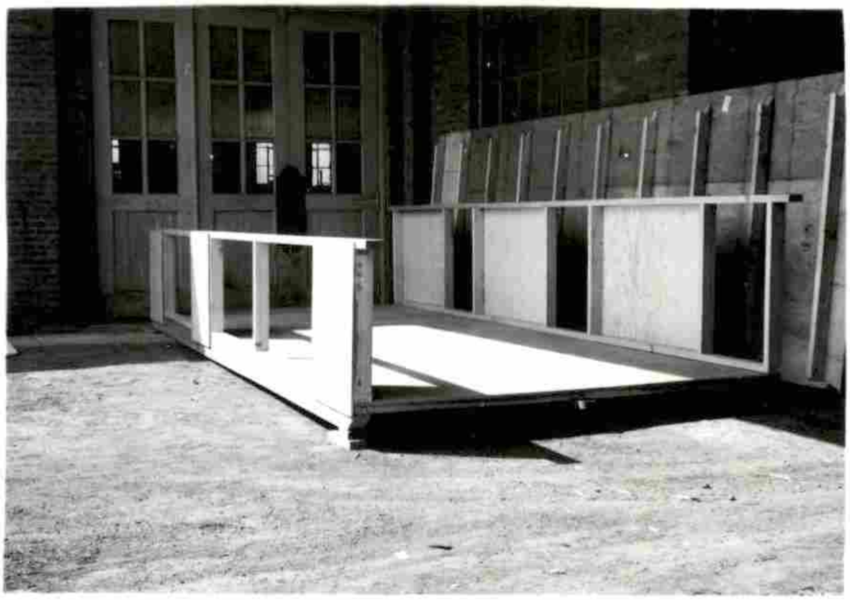


Fig. 7. Floor and Wall Sections Assembled

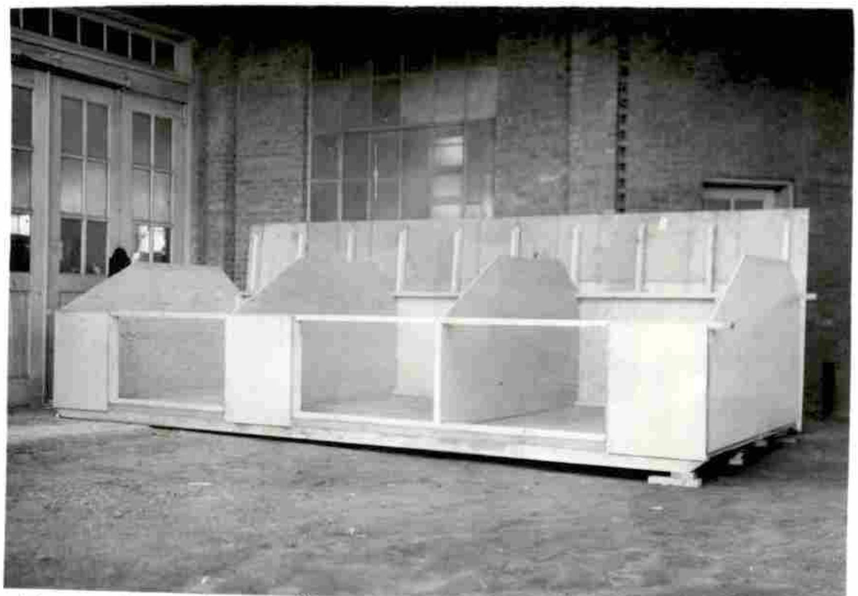


Fig. 8. View Showing Ends and Partitions in Position

Felt roll roofing was applied to the roof in the next step of the procedure. After two squares of roofing had been cut so as to cover the roof with a minimum of waste, the roofing was nailed to the sheathing. The lap on the rear section was made over the girt in that section. In the application of the roofing, the specifications of the manufacturer were followed.

Guard rails were installed next. Framing of 2" x 4" material was used and a combination of spiking to studs and blocking under the ends of the rails was used to secure the guard rails. As guard rails are a necessity in the farrowing pen, advantage was taken of their presence, and a thinner plywood partition was used than the design load of an impact load of 600 pounds would require.

The final step of the construction procedure was the painting of the house. Although the entire house was painted, the exterior surfaces and the floor were the only sections requiring paint, and even these could be left unpainted. The paint, however, presents a neater appearance, while at the same time it protects the wood from weathering.

Conclusions. The following conclusions were drawn from the experience gained in constructing the house:

1. The method of prefabrication and assembly by sections seems satisfactory for use as a construction procedure, especially where the work will be done in the lumber yard with power equipment.

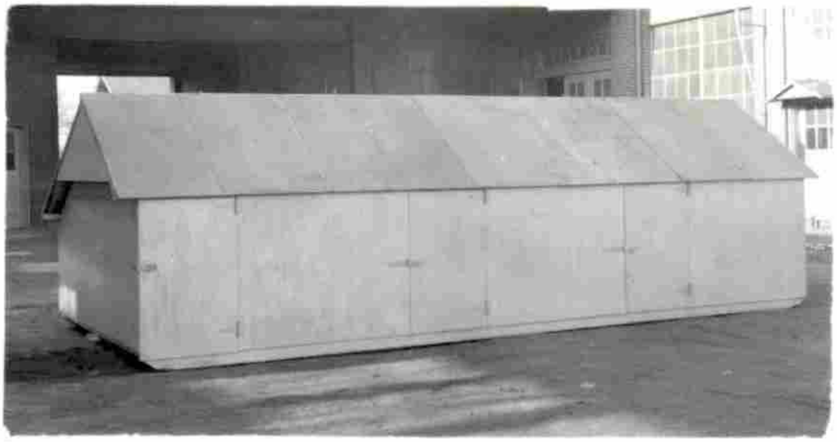


Fig. 9. Front View of Plywood Movable Hog House No. I.

Fig. 10. Front View with Front and Entrance Doors Open

Fig. 11. Rear View of Plywood Movable Hog House No. I

2. One man can do most of the work. Only in parts of the assembly process is the help of another man needed.

3. The preparation of a detailed, step by step procedure for construction seems advisable as an aid in reducing labor costs.

4. Plywood is easy to handle and apply in the construction of a plywood movable hog house.

Rigidity tests.

Introduction. As movable hog houses are subjected to severe racking while being moved, a test that closely approximated use conditions was run to see what effect such a loading condition would have on the plywood movable hog house.

Determination of method. The method used to test the plywood movable hog house was essentially the same as that used by Dunkelberg (7) in his test for rigidity of the plywood brooder house. He states the method thus:

> "If three corners of the shelter were fastened rigidly to supports, a load on the free corner would approximate the loads experienced by the shelter while being moved over rough ground."

Apparatus and method of procedure. A static test was made with the house fastened rigidly at the two corners of one and (Figure 12) and supported at the front corner on the other end. An Ames dial gauge was placed on the rigid corner opposite the load to see if any deflection of the fastening occurred. Then on the rear corner loads were applied and the deflection read with a dial gauge in thousandths of an inch

Fig. 12. Method of Fastening Structure for Deflection Tests

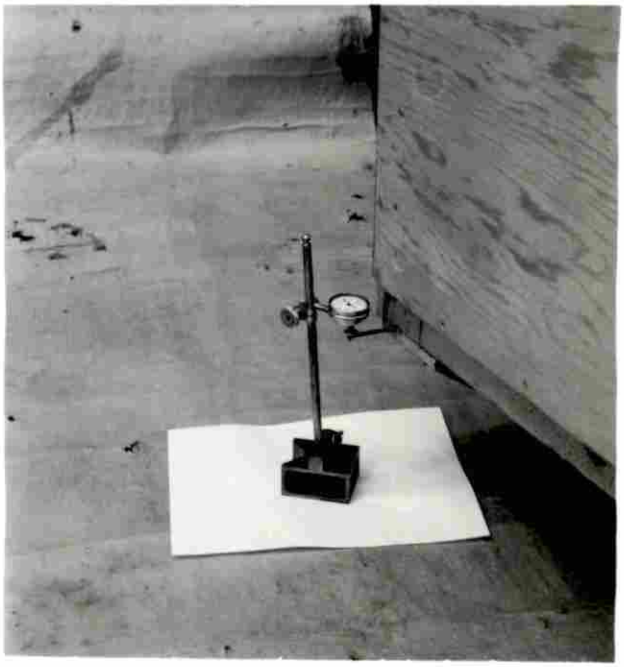


Fig. 13. Dial Gauge Used for Taking Static Loading Deflection Readings

(Figure 13). To obtain a zero reading the house was raised by means of a hydraulic jack placed under the free end on the axis of the center of gravity of the house. The dial gauges were set on zero and then the house was allowed to settle. The difference in readings of the supported corner and the free corner was the deflection of the house due to the weight of the house. The deflection gauge was again set on zero and increments of load of 60 pounds applied. The same procedure was followed with the rear corner supported and the front corner free. Table IV shows a record of the loads and deflection readings.

A vibratory test was made in the following manner. A small bench grinder with eccentric weights on the shaft in place of grinding wheels was fastened securely to the floor at the rear corner and the front corner was supported. Through the use of a variable speed motor to vary oscillations and the use of weights to increase the amplitude of the vibration, a vibration was secured with sufficient deflection to reproduce loads of over one-third the weight of the building at the rate of about 400 per minute. This rate of vibration was found experimentally by varying the speed of the motor and observing the point at which maximum deflection of the house appeared on the deflection tape. The house was allowed to vibrate for several minutes at that rate and then the number of vibrations on the tape were counted. Deflections and number of vibrations per minute were recorded for one minute

Table IV
Static Loading Before Vibration Test

Rear Section		Front Section	
Load (lbs.)	Deflection 1/1000 in.	Load (lbs.)	Deflection 1/1000 in.
0	0	0	0
60	22	60	22
120	48	120	49
180	72	180	79
240	97	240	105
300	122	300	131
360	149	360	159
420	173	420	186
480	203	480	215
540	219	540	238
600	243	600	265
660	272	660	297
720	295	720	326
780	322	780	349
840	343	840	372
900	369	900	402

Table V
Static Loading After Vibration Test

Rear Section		Front Section	
Load (lbs.)	Deflection 1/1000 in.	Load (lbs.)	Deflection 1/1000 in.
0	0	0	0
60	24	60	26
120	50	120	59
180	78	180	94
240	104	240	128
300	133	300	153
360	163	360	185
420	188	420	209
480	217	480	234
540	247	540	263
600	275	600	297
660	302	660	329
720	331	720	363
780	363	780	392
840	381	840	425
900	408	900	460

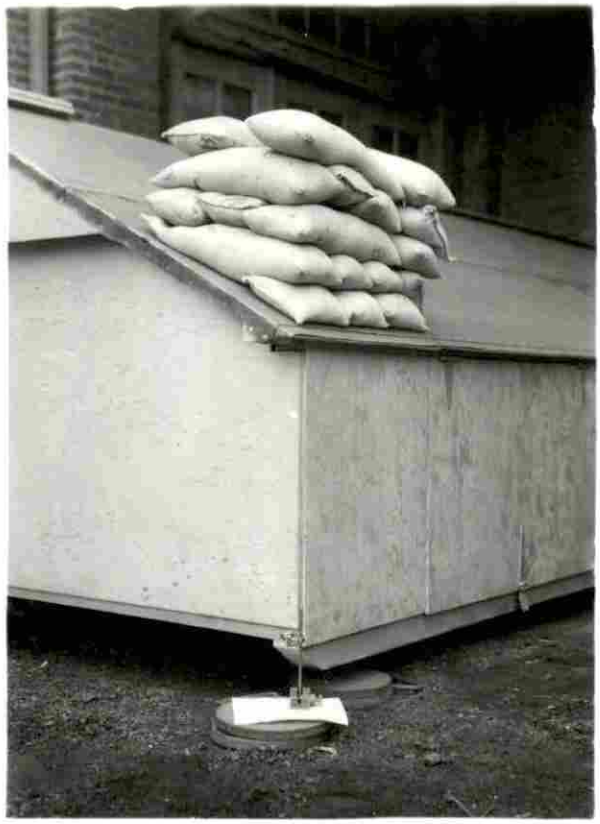


Fig. 14. Method of Applying Static Loads

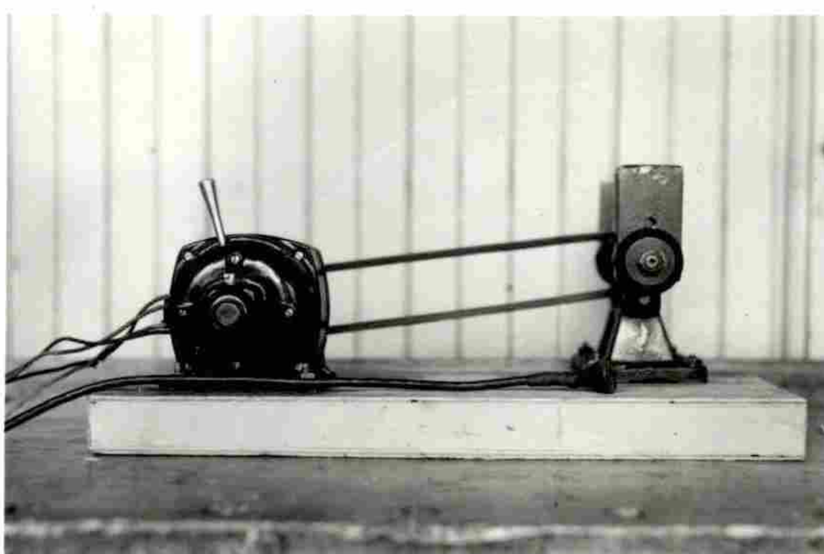


Fig. 15. Vibration Producing Apparatus

of every five on a moving tape as shown in Figure 16. The speed of the motor was varied as necessary to maintain the maximum deflection of the house for the condition of loading used. The vibrating apparatus is shown in Figure 15. The test ran for two hours and five minutes. The test readings are shown in Table VI.

Following the vibratory test a second static test was run to see what effect the vibratory test had on the rigidity of the structure. The same procedure was followed in the second static test as in the first test. Loads and deflections are shown in Table V.

The two static tests were plotted on a graph to show the relation between the applied loads and the deflection (Figure 18). By comparing the average deflection of the vibratory test with the two curves of the static tests, the average load during the vibration test was secured.

Results of tests. The load-deflection of the first static test for both front and rear loadings was a straight line (Figure 18) and a load of 900 pounds, or 9/16 of the weight of the building, deflected the rear corner less than 4/10 of an inch and deflected the front corner just over 4/10 of an inch.

In the vibratory test more than 50,300 loads of 580 pounds were applied. No evidence of failure was observed during the test.

The static test following the vibratory period showed a

Table VI
Vibratory Test

Time	Vibrations per Minute	Deflection 1/100 in.
2:50	420	24
2:55	420	24
3:00	430	26
3:05	420	25
3:10	400	26
3:15	400	27
3:45	400	25
3:50	400	25
4:00	410	25
4:05	410	23
4:10	400	23
4:15	410	25
4:20	410	25
4:25	400	26
5:00	400	27
5:05	400	25
5:10	390	25
5:15	390	26
5:20	400	24
5:25	390	24
5:30	380	24
5:35	400	27
5:40	400	26
5:45	390	24
5:50	390	25

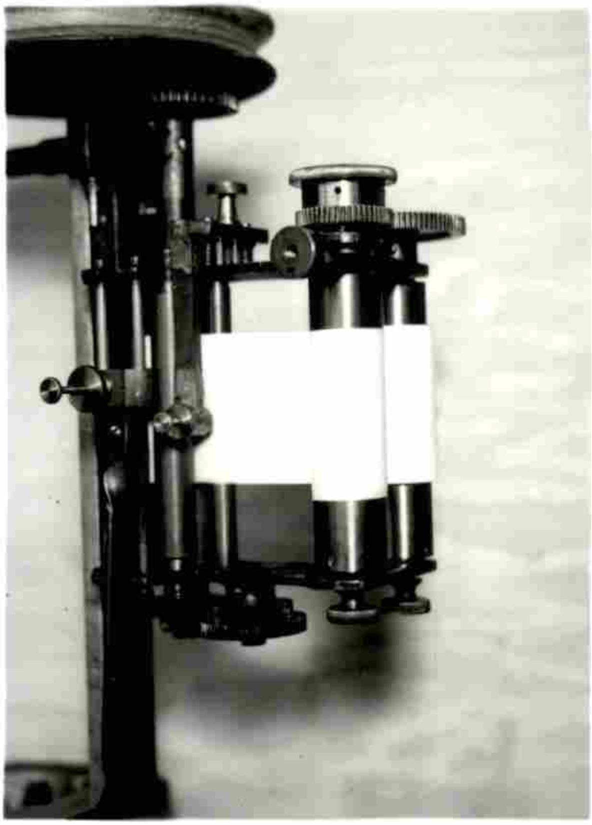


Fig. 16. Closeup of Vibration-
Deflection Recorder

Fig. 17. Vibration-Deflection Recording
Apparatus

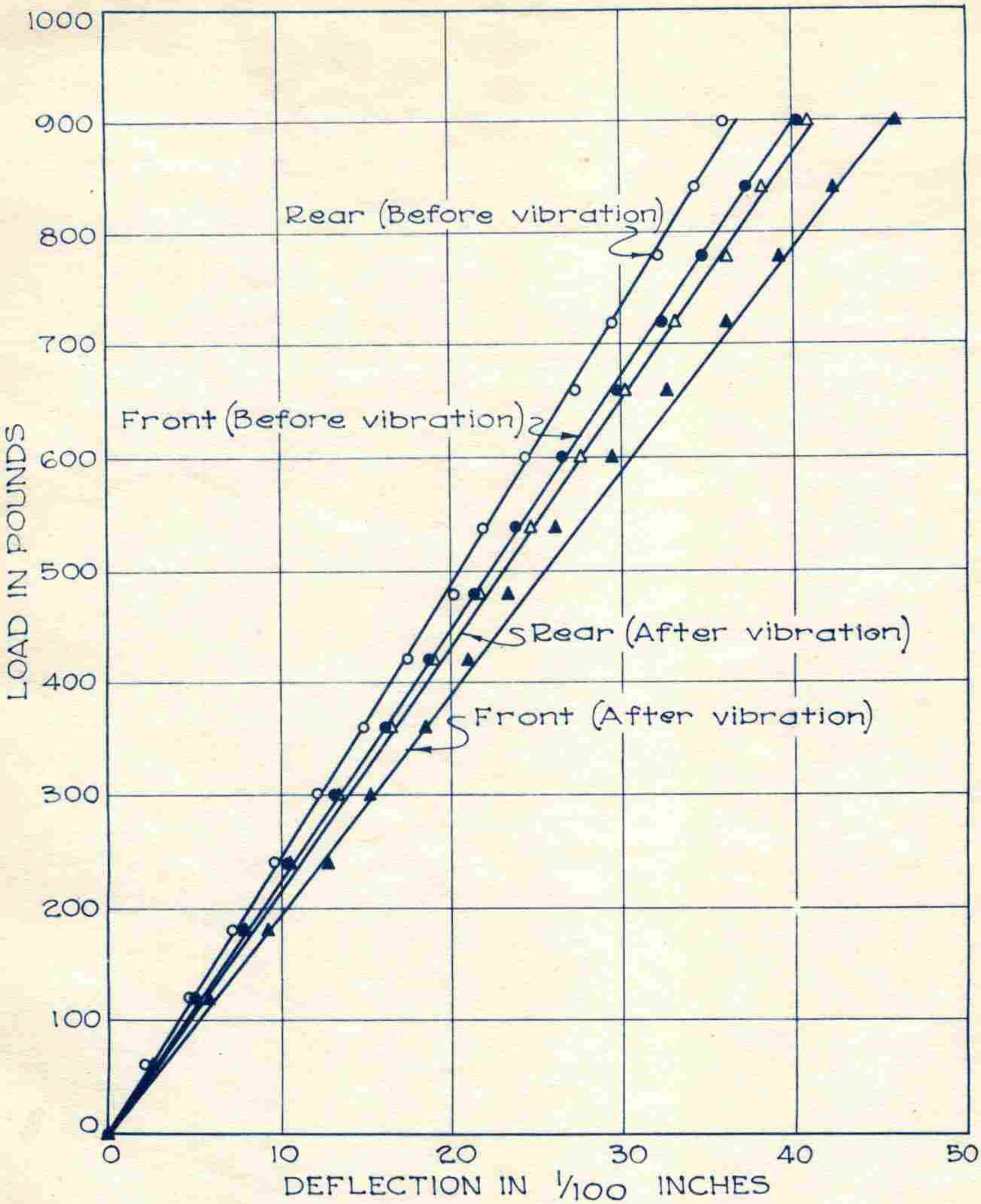


Fig. 18. Load Deflection Curves for Static Tests

load-deflection curve from 2 to 40 thousandths of an inch greater than the original static test for the rear corner and from 4 to 58 thousandths of an inch for the front corner. No damage to the plywood structure was evident.

Discussion of results. The test results indicate that even after the application of many loads, the plywood movable hog house was very rigid. The deflection of less than 1/2-inch was not sufficient to cause racking when a load of over one-half the weight of the building was applied at the free corner. Thus all loads applied were within the elastic limits of the structure, yet, it is only reasonable to suppose that the structure in ordinary use would not be subject to loads greater than those applied in the test.

The greater deflection of the front section over the rear section at first appeared odd, but when the comparative effect of the rear and front roofs on the rigidity of their respective sides was considered, this greater deflection appeared only normal.

Observations during tests. During the vibratory test several observations were made, namely: (1) entire house except the members in immediate contact with the fixed ends vibrated, indicating that the structure was acting as a unit; (2) at no time was the slightest evidence of failure observed; (3) accurate measurements of the deflections with a dial gauge would appear very difficult to obtain.

In the static tests, recovery from deflection was observed to be about 75% as the load was removed. Complete recovery was observed when the house was restored to its original position and then allowed to deflect under its own weight.

Conclusions. From the above results these conclusions were drawn:

1. Glued plywood construction is extremely rigid.

2. A plywood movable hog house constructed like the one tested should not rack to pieces under ordinary use.

3. The method of loading the structure with vibratory loads appears to simulate actual conditions very closely insofar as effect upon the structure is concerned.

4. The method of reading deflection and vibrations used in this test would appear to give more accurate results than a dial gauge and tachometer.

Comparison with conventional type.

Introduction. In order that some comparisons might be made between a conventional house and the plywood house, plan D-776 of the Iowa State College Extension Service (10) was reviewed. Time did not permit the construction and testing of this structure but some significant comparisons of weight, heat loss, and cost were made.

Weight. The weight of the plywood movable hog house was computed in the same manner as was the conventional type in the "Comparative Study of Present Type Movable Hog Houses." Then the house was weighed as a check on the accuracy of the computations. From the computations the conventional house was found to weigh 2,418 pounds and the plywood house 1,580 pounds. The actual weight of the plywood house was 1,530 pounds. A house weighing less than 1,600 pounds is light enough to be moved easily; therefore this saving in weight represents quite an advantage.

Heat loss. As heat is very seldom added in this type of farrowing house, some attention must be given to the heat lost from the structure.

A theoretical study was made of the heat losses of both the conventional house and the plywood house. The recommendations and formulas of the American Society of Heating and Ventilating Engineers (1) were followed in estimating the losses through heat transmission, ventilation and infiltration.

Heat losses from absorption, conduction and radiation were computed by use of this formula: $H = AU\ (t_i - t_o)$

where H = Btu per hour transmitted through the material.
A = area in square feet of the material.
$(t_i - t_o)$ = temperature difference between inside and outside air, assumed to be 40 degrees Fahrenheit.
U = overall coefficient of heat transmission of the section expressed in Btu per hour per degree difference in temperature; computed by the following formula:

$$U = \frac{1}{1/f_i + x/k + 1/f_o}$$

where $1/f_i$ = inside surface resistance, assumed to be 1/1.65.
x = thickness of material.
k = amount of heat in Btu transmitted in one hour through one square foot of material one inch thick.
$1/f_o$ = outside surface resistance, assumed to be 1/6.0.

Ventilation and infiltration heat losses were computed by the use of the following formula:

$$H_s = 0.018\ Q\ (t_i - t_o)$$

where H_s = heat in Btu required to warm incoming air.
Q = volume of outside air entering building.
$(t_i - t_o)$ = temperature difference assumed to be 40 degrees Fahrenheit.

The value of Q for the ventilating system of each house was computed from the formula:

$$Q_v = 9.4\ A \sqrt{H\ (t_i - t_o)}$$

where A = area in square feet of ventilator.
H = height from inlets to outlets in feet.
$(t_i - t_o)$ = temperature difference.

The value of Q for the infiltration through cracks in each house was computed from the formula:

$$Q_i = VL$$

where V = volume of infiltration in cubic feet per foot of crack per hour.
L = length of cracks in house, expressed in feet, divided by two to determine length of infiltration cracks, as other half of cracks are exfiltration cracks.

In choosing values for use in the formula, the value of V for cracks around doors, end, side and floor cracks, was taken to be equal to that of a poorly fitted window as given by the A.S.H.V.E. Guide for 1939 (1). Wind velocity was taken as 15 miles per hour. The value of V for roof cracks was taken equal to that of a well fitted window.

The heat loss from absorption, conduction and radiation for the plywood house was found to be higher than for the conventional, but this higher value was to be expected because of

Table VII
Comparison of Heat Losses

	Plywood		Conventional	
	U	Btu	U	Btu
Absorption, conduction, and radiation loss				
Roof	.766	5105	.58	3790
Floor	.722	4170	.36	2073
Ends	.722	867	.58	696
Sides	.722	2640	.58	2297
Total		12782		8856
	Air change cu. ft./hr.	Btu/hr.	Air change cu. ft./hr.	Btu/hr.
Ventilation loss (Doors closed)	14280	5141	3996	1439
	Air change cu. ft./hr.	Btu/hr.	Air change cu. ft./hr.	Btu/hr.
Infiltration loss:				
Doors	11271	4058	12591	4532
End cracks			7735	2784
Side cracks			9200	3312
Roof cracks			6020	2167
Floor cracks			15000	5400
Total	11271	4058	50546	18195
TOTAL		21981		28490

the thinness of the plywood panels. Ventilation heat losses were also higher since the ventilators on the plywood house are much larger than those on the conventional house.

The heat loss from infiltration of air into the house was found to be considerably lower for the plywood house than for the conventional. Indeed, the saving in heat losses by reducing drafts through the use of plywood was so great that the disadvantage of the thin wall panels was overcome, so that the total heat loss in Btu per hour for the plywood house was only three-fourths the total heat loss for the conventional house.

Cost. The true initial cost of the plywood movable hog house is difficult to determine. The cost shown for Plywood House No. I represents in all probability the highest cost for such a structure, inasmuch as the plywood items were shipped to Ames by local freight from Chicago. For this reason the cost of plyscord sheathing was higher than the cost of standard panels of higher grade because the latter were in stock in Ames. The sheathing grade was used because, theoretically, with complete stocks, this grade would be cheapest.

To illustrate the effect upon cost of special orders for plywood, the cost of Plywood House No. I was $124.87, while the same house could have been built of standard Sound 2 sides panels for $120.72. For this reason if specified grades are not in stock, substitutions may be cheaper than the specified grades.

An effort was made to determine what the cost of the house would be using sheathing grade plywood, on the assumption that this grade would be carried in stock at the lumber yards, but this effort was abandoned because such a cost would be misleading as sometimes the specified grades would not be in stock.

The labor cost for the plywood house was estimated to be slightly higher than for the conventional house chosen for the comparisons. However, if a house approaching that of the plywood house in soundness of construction had been chosen for the comparisons, the labor cost of such a house would be higher. For example, if the house compared with the plywood house had been constructed of flooring instead of 1" x 6" and 1" x 12" boards, the number of hours required for construction would have been about 30, not 22.7. The labor cost would then have exceeded that of the plywood house.

The cost per house would be lowered by using the detailed procedure set forth in this study, and by building two or more houses at the same time. Certain pieces of plywood may be used in this way that perhaps would be discarded otherwise. Then, too, the practice thus obtained would reduce the labor cost.

The annual costs for the conventional house and the plywood house were computed after reviewing the recommendations of Wooley (21) and the test results. Interest was computed at the rate of 6 percent for the average value of the house, which would be one-half the initial cost. The rate of depreciation for the plywood house was taken as 4.0 percent;

the rate for the conventional house was taken as 7.5 percent. These values correspond to a useful life of 25 years and 13-1/3 years, respectively. The repair rate for the plywood house was taken as 5/10 percent, or one-third that of the conventional house, for with the possible exception of the roof no repairs should be necessary for the plywood house. Insurance and taxes were computed at the same rate for both houses. These costs represented only a very small proportion of the total annual cost.

From the annual cost estimates Plywood Movable Hog House No. I costs 16 percent less per year than the conventional. This indicates that while the plywood house may have a higher initial cost, it is cheaper in the end than the conventional house.

<u>Conclusions</u>. The comparisons made in the foregoing discussion justify the following conclusions:

1. The weight of a three-pen, 8' x 18' movable hog house can be reduced from 2,400 pounds to less than 1,600 pounds through the use of plywood.

2. The plywood house will be much warmer than the conventional, for the elimination of drafts more than offsets the 2
effect of thin plywood panels on the heat lost from the structure.

3. Although the plywood house has a higher initial cost than the conventional, it will cost less over a period of years.

Table VIII
Comparison of Weight, Heat Loss and Initial Costs of Movable Hog Houses

Type of House	Wt. in Lbs.	Heat Loss in Btu	Cost: Materials: Lumber	Cost: Materials: Plywood	Cost: Materials: Hardware	Cost: Materials: Total	Cost: Labor @ .50: Hrs.	Cost: Labor @ .50: Total	Cost: Total
Conventional	2418	28490	$69.02	$ --	$13.13	$ 82.15	22.7	$11.35	$ 93.50
Plywood Movable Hog House No. I	1530	21981	22.68	71.19	18.50	112.37	25.0	12.50	124.87
Plywood Movable Hog House (Using Grades in Stock in Ames)	1530	21981	22.68	67.04	18.50	108.22	25.0	12.50	120.72

Table IX
Estimated Annual Cost of Movable Hog Houses

Type of House	First Cost	Interest: Aver. Value	Interest: Annual Int. @ 6%	Depreciation: Rate	Depreciation: Annual	Repairs: % First Cost	Repairs: Annual	Ins. and Taxes: Aver. Value	Ins. and Taxes: Ins. @.4%	Ins. and Taxes: Tax. .1%	Total Annual Cost
Conventional	$93.45	$46.78	$ 2.82	7.50	$ 7.01	1.50	$ 1.40	$46.78	$.19	$.05	$11.47
Plywood Movable Hog House No. I	124.87	62.44	3.75	4.00	4.99	.50	.62	62.44	.25	.06	9.67
Plywood House (Using Grades in Stock in Ames)	120.72	60.36	3.62	4.00	4.83	.50	.60	60.36	.24	.06	9.35

Suggestions for further work.

Review for economy. During the construction and testing of Plywood Movable Hog House No. I certain changes which perhaps would materially reduce the cost were observed. Time did not permit an investigation of these possible changes and for that reason they are listed here in the hope that at some future date these changes may be investigated.

These changes are:

1. Substitution of 2" x 2" rafters for 2" x 4" rafters.
2. Substitution of 2" x 2" stiffeners for 2" x 4" stiffeners.
3. Substitution of 5/16" sheathing for 3/8" sheathing for the interior partitions.
4. Substitution of Plyform grade of plywood on the exterior walls for DFPA-Ext.

Time and use tests. Time and use tests on the plywood house should prove quite worthwhile. An investigation of the moisture content of the wood inside a hog house and the effect of this moisture upon plywood should prove of value in determining what grades of plywood would be most suitable. A use test would provide information with which to prove or refute the estimated life of the structure as set forth in this study.

Detailed construction procedure.

Introduction. During the construction of the plywood movable hog house the need for a detailed construction procedure became apparent. Such a procedure would greatly reduce the time required for construction by simplifying the process. Therefore, the following procedure, listed step by step for simplicity and clarity, was developed.

Floor section. 1. Cut three 4" x 4" runners 18'-0" long and bevel ends to a 30 degree angle with the horizontal.

2. Attach clevis hitches to one runner and use this runner as center runner.

3. Spread creosote over bottom and half way up sides of runners.

4. Cut four 2" x 4" joists 8'-0" long and six 2" x 2" joists 8'-0" long. Cut three 2" x 4" stiffeners 1'-8-1/2" and twenty-four 2" x 4" stiffeners 1'-9-1/4".

5. Mix 3 pounds of self-bonding water-resistant casein glue in 6 pounds of water.

6. Mark 2'-0" spacing of joists on runners. Place and square up runners through use of 5/16" sheet plywood tacked on one end to runners. Runners are spaced as shown on plan.

7. Spread glue on ends of joists and nail in place on runners according to framing plan. 2" x 4" joists are placed flat. Nails where possible should be spaced about 4 to 5 inches apart. Use 4d com. with 5/16" and 3/8" sheathing and 6d com. with 1/2" plywood.

8. Spread glue on stiffeners and fasten in position between joists on runners.

9. Rip one piece of 1/2" plyscord sheathing 4'x 8' to

2'x 8'.

10. Spread glue on stiffeners and joists and nail 2'x 8' strip in place. Continue process for the other 4'x 8'-1/2" sheathing panels. Joints are made on 2" x 4" joists.

Front wall section. 1. Cut seven studs 2" x 4" x 2'-10-1/2"; cut one 2" x 4" x 18'-0" shoe sill; cut one 2" x 4" x 18'-10-1/2" plate.

2. Lay out studs, shoe sill and plate according to plan using floor section for a square and straight edge. End-nail studs in place to plate and sill.

3. Mix 1/2 pound of casein glue in 1 pound of water.

4. Cut 5 plywood sheets of 1/2" D.F.P.A.-Ext. as shown on sheet 3 of plan.

5. Spread glue on sill, studs and plate and fasten front panels in position; note the spaces for doors and observe 1-1/4" lap of plywood on plate.

Rear wall section. 1. Cut seven studs 2" x 4" x 2'-2-1/2"; cut one 2" x 4" x 18'-0" shoe sill; cut one 2" x 4" x 18'-10-1/2" plate.

2. Lay out studs, shoe sill and plate according to plan and nail studs as in step 2 of front wall section.

3. Mix 1/4 pound of glue in 1/2 pound of water.

4. Spread glue on sill, studs and plate and nail in position; observe precautions of spacing of step 5 of front wall section.

Rear roof section. 1. Cut 10 rafters 2" x 4" x 5'-8" and 2 rafters 2" x 2" x 5'-8"; make plumb cut according to plan.

2. Mix 1 pound of glue in 2 pounds of water.

3. Lay out rafters on floor section according to plan and tack to floor.

4. Spread glue on rafters for each plywood panel as it is placed. Panels are cut from 5/16" sheathing as shown in detail on sheet 3 of plan.

5. Nail panels to rafters.

6. Cut ridge 2" x 4" x 18'-9-1/4" and bevel upper edge to fit roof slopes.

7. Place ridge in position on rear roof section, glue and nail in place; nail sheathing to ridge.

8. Cut nine 2" x 2" x 1'-9-1/2" nailing girts for roofing. Glue and nail in position according to plan.

Front roof section. 1. Cut 10 rafters 2" x 4" x 3'-6" and 2 rafters 2" x 2" x 3'-6"; make plumb cut according to plan.

2. Cut 5/16" sheathing as shown in detail, sheet 3 of plan.

3. Mix 1/2 pound of glue in 1 pound of water.

4. Place rafters as shown on plan and tack in position on floor.

5. Spread glue for one section at a time, place panel and nail.

6. Follow same procedure for all four sections; observe carefully all door spacings.

Front doors. 1. Mix 1 pound of glue in 2 pounds of water. This amount of glue will be sufficient for all doors.

2. Cut 6 framing members 2" x 2" x 2'-8-1/2"; ends beveled 45 degrees. Cut 6 framing members 2" x 2" x 1'-9-1/4"; ends beveled 45 degrees. Cut 2" strip from top of door panel.

3. Spread glue on framing members; place according to detail plan and nail.

Rear doors. 1. Cut 6 framing members 2" x 2" x 2'-0-1/2"; ends beveled 45 degrees. Cut 6 framing members 2" x 2" x 3'-10"; ends beveled 45 degrees. Cut 2" strip from top of door panel.

2. Spread glue on framing members; place according to detail plan and nail. Use surplus glue mixed for front doors.

Roof doors. 1. Cut 6 framing members 2" x 2" x 1'-10"; ends beveled 45 degrees. Cut 6 framing members 2" x 2" x 3'-0"; ends beveled 45 degrees.

2. Spread glue on framing members; place according to detail plan and nail. Use surplus glue mixed for front doors.

Assembly. 1. Level floor section by blocking under corners where necessary.

2. Mix 3 pounds of glue in 6 pounds of water.

3. Spread glue on bottom of shoe sill and overlap of plywood of the front wall section.

4. Place front wall section in place on floor and nail, using 16 or 20d com. nails. Cut out sill in the three doors.

5. Spread glue on rear wall section as on front section

and nail to floor in a similar manner.

6. Cut end wall panels as shown in detail, sheet 3 of plan.

7. Spread glue on end wall studs and edge of floor and end joists. Nail panels in place, take care to see that house is plumb.

8. Cut interior partitions according to plan.

9. Cut two 2" x 2" x 7'-4-3/4" sills for interior partitions. Spread glue on sills and nail in place.

10. Spread glue on sill and studs for interior partitions, place panels, and nail.

11. Lift rear roof section into position and place front roof sections.

12. Spread glue on front bevel of ridge and nail front sections to rear section and to front wall section. Observe carefully all door spacings.

13. Nail end panels and partitions to their corresponding rafters. Cut ventilator panels according to detail and glue in place.

14. Place roof doors using two 4" T hinges for each door.

15. Cover front and rear roof with roll roofing, following specifications of manufacturer and details shown on sheet 3 of plan. Place roof edging along the top and nail into edge of plywood.

16. Place and glue the 2" strips cut from front and rear doors to the plate at their respective locations.

17. Hang front and rear doors, using 4" T hinges for front

doors and 5" T hinges for rear doors. Place 6" hinge hasps on front and rear doors.

18. Install pig fenders according to detail plan. Fender across rear is made removable by fastening with 1/2" x 4" bolt. Blocks under fenders are spiked to floor and walls.

19. Paint house the desired color; be careful to seal edges of plywood exposed to weather.

SUMMARY

1. The requirements of movable hog houses were reviewed.

2. The properties of plywood and the advantages of plywood construction were reviewed.

3. The objectives of the study were to design a plywood movable hog house to meet the criteria of light weight, low cost, great strength and ridigity and maximum comfort for the hogs, and to develop a simple procedure for the construction of the house designed to meet the above requirements.

4. A comparative study of present type movable hog houses was made.

5. The size, shape, number and size of openings, height of walls, pitch of roof, grade of plywood and method of fabrication to be considered in this study were established.

6. The design load and loading conditions for a movable hog house and the assumptions in design were determined.

7. A three-pen, 8' x 18' plywood movable hog house was designed and constructed.

8. The house was tested to determine its rigidity and strength under conditions approximating actual use.

9. Comparisons of weight, heat loss and cost of the Plywood Movable Hog House and a conventional type of house of equal size were made.

10. Suggestions for further investigations were stated.

11. A detailed, step-by-step procedure for construction of the Plywood Movable Hog House was developed.

CONCLUSIONS

1. Present type movable hog houses of three pens or more are too heavy to be moved easily.

2. Type of construction as well as size of house has a great influence on the cost and weight of movable hog houses.

3. Glued plywood construction is one means of securing strength and rigidity and light weight in movable hog houses.

4. The plywood movable hog house designed in this study has the following advantages which should make it acceptable to swine herdsmen in Iowa:

a. It weighs about 1,500 pounds as against 2,400 pounds for the conventional type and is therefore much easier to move.

b. Heat losses from the house are lower than from the conventional house. ?

c. The annual cost of the plywood house is less than that of the conventional type.

d. The house will not rack to pieces under normal handling even after repeated moving.

5. The three-pen plywood movable hog house is well adapted to prefabrication in the lumber yard where power equipment is available.

6. The cost of the three-pen plywood movable hog house will be comparable to that of the conventional if suitable plywood grades are available in stock at the same place at which the material for the conventional house would be secured. ?

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